Restoration on abandoned tropical pasturelands—do we know enough?

Singarayer K. Florentine*, **Martin E. Westbrooke**

School of Science & Engineering, University of Ballarat, P.O. Box 663, Victoria 3350, Australia

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*Corresponding author. Tel: +61-3-5327-9231; fax: +61-3-5327-9240.
E-mail addresses: s.florentine@ballarat.edu.au (S.K. Florentine), Mew.staff@ballarat.edu.au (M.E. Westbrooke).

Introduction

Why do we need to restore abandoned and degraded pasturelands?

Tropical rain forest is one of the most complex, and self-sustaining ecosystems on the planet. However, in recent years, tropical rainforests have been vanishing at an alarming rate. Whitmore (1997) reported that within the last ten years tropical rainforests have had an annual loss of 0.8% of area. Laurance et al. (2001) reported on average nearly two million hectares of forests have been disappearing in Brazil per year. Studies showed that the deforestation rate of Sri Lanka is around 3.5%, the third highest in the Asia Pacific Region (Food Agriculture Organization, 1988). These tropical rainforests have been converted for economic reasons, mainly cotton, coffee, banana and sugar cane plantations. Anderson (1990) and Hecht (1993) have pointed out that conversion to pasture for cattle grazing has had a significant impact on tropical rainforest. In Australia's Atherton Tablelands, aerial photographs show that some cleared tropical rainforest areas had been opened or grazed for approximately 50 75 years but for number of reasons a significant amount of this converted land has been abandoned. Approximately 60,000 km^2 of Amazonian land are in pasture (Toledo & Serrao, 1982). Once these converted lands are abandoned, forest recovery will take many years. Uhl, Buschbacher, and Serrao (1988) predicted these abandoned lands may never develop into forest.

It is anticipated that the abandoned pasturelands may become anthropogenic grasslands and/or secondary forests over time (Brown & Lugo, 1990; Buschbacher, 1986; Buschbacher, Uhl, & Serrao, 1984). However, the recovery from grassland to secondary rainforest, will take a significant time. To convert these abandoned pasturelands into secondary forest, human intervention through tree planting is a vital part (Lugo, 1992). There are major reasons why we need to restore damaged tropical rainforest. The first reason is most countries have protected less than 5% of the original rainforest; therefore we need to increase the area of rainforest by restoring with native plant species (Aide, 2000). The second is to maintain biodiversity (Brown, 1993; Phillips et al., 1998). A significant amount of money, time and energy has been spent on restoring degraded and abandoned lands throughout the world but the question yet to be answered is: do we know enough about restoration techniques for degraded and abandoned pasturelands? What are the barriers to natural recruitment in abandoned pasturelands?

Barriers to restoration

A study conducted by Aide, Zimmerman, Pascarella, Rivera, and Marcano-Vega (2000) examined the fate of pasturelands once abandoned. Will colonising native seedlings species move towards secondary forest or will these lands develop into a different and unique habitat? Several studies have shown that, once pasturelands have been abandoned, native species seedling recruitment is poor (Buschbacher, 1986; Aide, Zimmerman, Herrera, & Rosario, 1995 and Aide et al., 2000; Cubina & Aide, 2001). A recent study by Zimmerman, Pascarella, and Aide (2000) examining barriers to forest regeneration in an abandoned pasture in Puerto Rico showed that the major factors were lack of soil seed bank, and seed rain input. Similarly Richards (1996), Cubina and Aide (2001) and Florentine, Craig, and Westbrooke (2003) pointed out that factors which could delay or slow forest recovery were: shortage of tree seeds, seed and seedling predation, drought, competition with established grasses/weeds, exhaustion of soil nutrients, changes in soil physical properties and absence of soil mycorrhizae.

Weeds and restoration

Invasion of exotic species into abandoned lands or fragmented forest landscapes is inevitable. Once they have invaded, they alter the structure and function of the area (Vitousek, Antonio, Loope, & Rejmanek, 1997; Horvitz, Pascarella, McMann, Freeman, & Hofstetter, 1998). These invaders prevent native species colonisation in several ways. Thick weed cover may prevent the native species seed from reaching the soil (Aide et al., 1995). Even if native species reach the ground, invaders compete for nutrients and moisture with newly recruited seedlings (Vieira, Uhl, & Nepstad, 1994; Nepstad, Uhl, Pereira, & da Silva, 1996). In addition, Whelan, Wilson, Tuma, and Soulaz-Pinta (1991) found that in degraded grasslands predation eliminates significant numbers of seeds within a few weeks of seed arrival.

Soil properties

Information on the changes in soil properties before and after deforestation and under grazed pasture and/or under anthropogenic pasture or secondary forests is scarce (Johnston, 1992; Reiners, Bouwman, Parson, & Keller, 1994). Jusoff (1989) reported significant changes in selected soil properties subsequent to recreational use of a forested reserve in Malaysia. The major changes were; increases in bulk density, compaction, soil erosion, and runoff, decreases in infiltration porosity, and water-holding capacity. Similar information for deforested pastureland turned to anthropogenic grassland and/or secondary forests is scarce for the tropical rainforest listed as a Natural Heritage Reserve by the UN, in north Queensland, Australia.

Rasiah, Florentine, Williams, and Westbrooke (2004) conducted a study in a paddock in the wet tropical North Queensland, Australia, which was deforested ≈ 60 yrs ago and was under unfertilised grazed beef pasture for ≈ 30 yr and under abandoned fallow for ≈ 30 yr. A section of the abandoned fallow paddock was artificially reforested with native forest species during the last ≈ 10 yr. They investigated two aspects firstly, whether any significant changes have occurred in selected soil physico-chemical properties, secondly whether artificial reforestation of abandoned pasture, using different native forest species for 10 yr, had any influence in reversing the changes that occurred after deforestation. It was found that regardless of the form of N or C, their concentrations were significantly lower under the abandoned pasture or in the reforested plots than in the undisturbed rainforest. Further the soil organic matter under the deforested system was $\approx 29{,}000$ mg/kg soil compared to $\approx 75{,}000$ mg/kg under rainforest. Other elements: EC, Ca, Mg, Na, K, and Al followed similar trends to organic matter. They concluded that resting of land through pasture abandonment for ≈ 30 yr and then after a further ≈ 10 yr of reforestation seem to have little or no influence in reversing deforestation induced changes in soil properties.

Seed supply

For tropical rainforest species, soil surface microclimate is very important for successful germination. Germination rate and subsequent survival rate is very high if the soil moisture and temperature are conducive (Fox, 1976). Even if the microclimate is suitable however, without enough seed supply into abandoned lands recruitment will be nil. Therefore seeds dispersing into a reforested site are important in enhancing the reforestation and this will accelerate the recovery process. Seed supply from natural forest to abandoned lands however is very poor. Aide and Cavelier (1994) found few seeds disperse more than 10 m from the forest edge and seedling numbers declined to nearly zero, 20 m from the forest edge. In a study conducted in Puerto Rico, out of 35 species producing fruit in the surrounding forest, only five species were detected in the seed rain or seed bank >4 m from the forest edge (Cubina & Aide, 2001). Another study showed that animal facilitated seed rain decreased with increasing distance from the forest edge, with most seed rain within 30 m of the forest edge (Charles-Dominique, 1986; Gorchov, Cornejo, Ascorra, & Jaramillo, 1993). Lack of seed movement from the primary rainforest to abandoned pasturelands or reforested lands is dependent on several factors. Most tropical rainforest trees and shrubs are depend on animals, however, considerable numbers of animals such as frugivorous, and bats avoid large open areas where they could be easily targeted by predators (Howe & Smallwood, 1982). Several studies have shown that frugivore birds visiting degraded pasture from forest remained within 80 m of the forest (da Silva, Uhl, & Murray, 1996). This emphasises the fact that in most restoration programs species selection is important. Significant numbers of fast growing and fruit and flower producing trees may help to bring seed dispersal agents into the restored sites. Prolonged pastoral activity depletes soil nutrients, fostering establishment of fast growing grass species, seasonal drought, lack of soil nutrients, soil compaction and lack of mycorrhizae.

Restoration techniques: do we know enough about direct seeding, seedling transplant, stem cuttings, plantation or artificial perching structures?

In highly degraded or abandoned pasturelands, soil stored seed bank of native species composition is very poor, mainly because tropical rainforest seeds cannot stay in the soil for a long period (Whitmore, 1997). In addition, tropical rainforest seed dispersal agents such as birds and mammals may not utilise the open pasturelands very often. Under these circumstances direct seeding or transplanting of seedlings is essential (Wunderle, 1997). Studies have shown that human intervention in pasturelands may facilitate and accelerate the re-colonisation of tropical rainforest species. But restoration ecologists are struggling to determine which techniques are most appropriate to follow to restore degraded and abandoned pasturelands in tropics. Chapman and Chapman (1996) suggested that plantations are one alternative way to accelerate natural regeneration of native species on abandoned pasturelands. Further techniques, such as broadcasting of seed, and cutting of native tree species must also be examined. It is widely accepted that one cannot simply introduce primary forest species (either seed or seedling) into abandoned pasturelands, mainly because primary forest species may not survive under full sunlight, or high soil temperature (Whitmore, 1991). Lugo (1992) proposed that artificial tree planting should be exercised on the abandoned lands to accelerate recovery process. In rainforest succession, colonisation of pioneer species creates a suitable condition for climax species to germinate and grow. Pioneer species grow fast and must produce canopy as quickly as possible. This will reduce the weed cover and create a favorable microhabitat and microclimate for climax species to germinate. In addition, pioneer species are attractive to birds and mammals, which are major seed dispersal agents (Whitmore, 1997; Goosem & Tucker, 1995; Wunderle, 1997). Therefore, to restore abandoned pastureland, pioneer or secondary species are the preferred candidates. The question is, how to achieve this? By direct seeding, planting single pioneer species, planting groups of pioneer species? Planting a combination of pioneer and secondary (climax) species, planting stem cuttings or manipulation such as providing artificial perching structures?

In general, two approaches have been followed in artificial recruitment. Direct seeding is less expensive, but major disadvantages are poor germination early seedling growth, high mortality, and severe weed competition (Evans, 1982). The alternative approach, widely followed, is the planting of forest species seedlings raised in nurseries but this is expensive (Evans, 1982).

Direct seeding

Direct seed broadcasting is where the seed is sown directly into the ground in abandoned lands. Aerial seeding was introduced during 1930s to restore eroded lands. Unfortunately seed loss was very high, because of the wind influence leading to uneven seedling distribution, and some areas having dense regeneration and others no seedlings at all. Studies conducted by Sun, Dickinson, and Bragg (1995) in the Atherton Tablelands, Australia, found that in direct seeding of pioneer species *Alphitonia petriei* (uncoated) seed germination rate was higher than seed coated with fertiliser and fungicide, insecticides in both controlled and field conditions. They found however that subsequent growth and survival of germinated *A. petriei* seedlings were hindered by already established neighbouring weed species. Steven (1991) suggested that success of direct seeding depends on, target species, soil condition, site preparation and technique for seed germination. Similarly, Garwood (1989) pointed out that seed destruction by animals also play a vital role in reducing seed germination. She stressed that further research is needed to develop techniques to reduce damage caused by seed predators. However, except some studies conducted by Crouch and Radwan (1975) and Venning (1985) recommending seed coating and pelleting as a protector against seed predators, little is known about this technique in tropical situations. Sun et al. (1995) concluded that, coupled with a suitable technique to break seed dormancy, *A. petriei* seed germination can be achieved with minimal effort, however, weed control and maintenance of nutrient levels are essential for success.

Planting seedlings

Another method of restoring degraded or abandoned pasturelands is using seedlings grown under controlled condition. However, most restoration groups in tropical forest areas are still in the initial stages of determining which species or species combination are more suitable to restore degraded or abandoned pasturelands. Goosem and Tucker (1995) proposed that two major types of tropical rainforest restoration could be adopted in Australian systems: framework species method (FSM), and maximum species diversity method (MSDM). In the FSM, one or a group of fast growing species are planted to provide a good canopy, and suppress weed species in a short period of time (approximately 1.5 2 years). The major advantages of this technique are: (i) it needs only a single planting and (ii) it is self-sustaining. However this technique is only suitable to areas where native vegetation is located close by. In the MSDM, a larger percentage of species are from the mature phase and primary promoters are generally avoided. The major disadvantage is the slower growth rate of many mature phase forest species, which requires intensive post planting management.

Florentine and Westbrooke (2004) conducted a study on a nine-year-old restored site in an area 30-years after abandonment of pasture (Fig. 1). The main objective of their study was to examine whether different restoration techniques (FSM & MSDM) had any influence on natural recruitment. They found that 239 seedlings occurred in FSM where, *Omalanthus novo-guineensis* seedlings were planted with eight primary promoter species, followed by 99 seedlings in maximum species diversity method, 36 in FSM where *A. petriei* seedlings were planted with eight primary promoter species, 10 in FSM where pure *Omalanthus novo-guineensis* seedlings were planted and 13 in the control (pastureland).

In another study, conducted by Tucker and Murphy (1997) in seven-year-old restoration sites from the Wet Tropics North Queensland, 72 plant

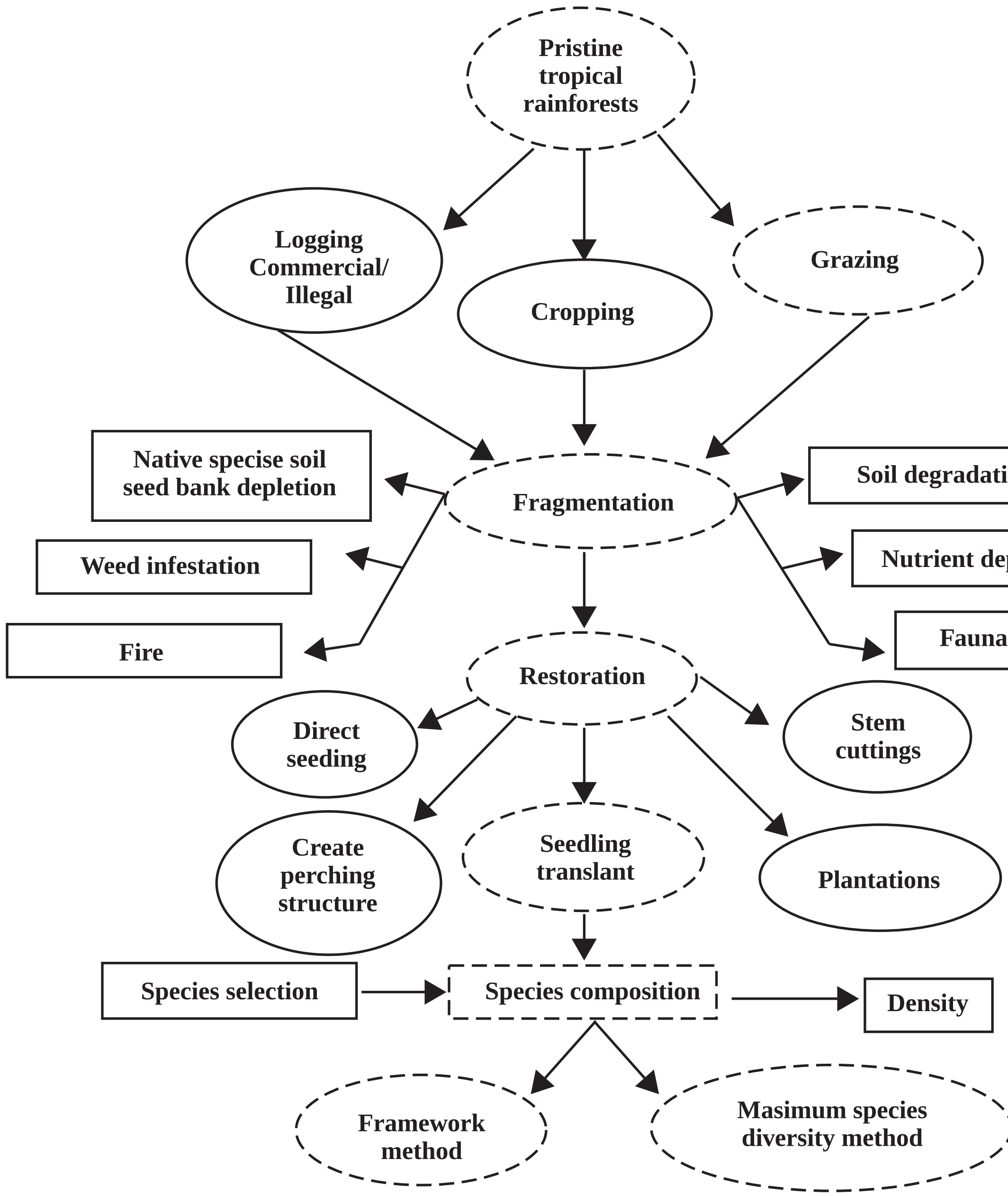

Figure 1. Fragmentation and restoration pathway in abandoned pasturelands. Discontinued lines show the study conducted by Florentine and Westbrooke (2004).

species were recruited. Most early successional species recruited in the study sites were zoochorous taxa. They also found that a variety of seedlings recruited in the restored sites were bird dispersed. This confirmed that restoration on abandoned lands are attracting fauna species and providing suitable condition for native species to germinate.

Stem cuttings

Stem cuttings have been extensively used in horticultural programs. This technique may be useful, particularly for plant species difficult to germinate or which take considerable amount of time to germinate. However, stem cutting using native tropical rainforest species has not been thoroughly investigated. *Ficus* species are good for restoration programs, because fruits (falls-fruits) are attractive to pigeons and pigeons are capable of dispersing seeds over a longer range (Goosem & Tucker, 1995).

Florentine (unpublished data) conducted a pilot study on five tropical rainforest *Ficus* species stem cuttings to examine their success rate: *F. pleurocarpa* ($n = 140$), *F. congesta* ($n = 133$), *F. obliqua* ($n = 360$), *F. watkinsiana* ($n = 98$), and *F. hispida* ($n = 122$). It was found that *F. congesta* showed a highest success rate (*F. pleurocarpa* (7.14%), *F. congesta* (61%), *F. obliqua* (3%), *F. watkinsiana* (14%), and *F. hispida* (18)). Initiation of buds also varied from species to species. Nine days after *F. congesta* stems produced most new buds (14%), followed by *F. pleurocarpa* (5%), *F. watkinsiana*(4%), *F. obliqua* (3%) and *F. hispida* (5%).

Restoration through cash crops

Engel and Parrotta (2001) pointed out the importance of developing techniques where landowner and ecosystems can benefit. Several studies have been carried out to examine forest plantations as a technique (using either seedling or seeding) in matching long-term ecosystem benefit with socio-economic benefit (Brown & Lugo, 1990). This method has wide acceptance with both landholders and ecologists (Lugo, 1992; Parrotta, Knowles, & Wunderle, 1997; Engel & Parrotta, 2001). Studies have also shown that forest plantations provide economic benefit by producing timber and create a conducive atmosphere for native species to grow (Soni, Vasistha, & Kumar, 1989; Lamb, Parrotta, Keenan, & Tucker, 1997; Lamb, 1998; Parrotta & Knowles, 1999). Chapman and Chapman (1996) conducted a study on exotic plantations and the regeneration of natural forests found a total of 1341 seedlings from 47 species within the plantations. They indicated these newly recruited indigenous seedlings were not from the soil seed bank, because the planted areas had been grasslands for several years and these sites have also been burnt repeatedly. Keenan, Lamb, Woldring, Irvine, and Jensen (1997) also tested the hypothesis that tree plantations may catalyse the regeneration of natural forest diversity. Their studies focused under the *Pinus caribaea* and *Araucaria cunninghamaii*, *Flindersia brayleana* and *Toona ciliata* ranging from 5 to 63 years plantations in Northern Australia. A total of 350 out 176 were tree species. They also calculated that 80 90% of seedlings recruited under the plantations were dispersed by birds.

Artificial perching model using branches of pioneer species

Considerable work has been carried out to examine whether artificial perching structures can attract avian fauna. McDonnell and Stiles (1983), McDonnell (1986), and McClanahan and Wolfe (1993) examined artificial perching in temperate zones and found that these artificial features do attract birds. Such artificial features are important in degraded abandoned pasturelands to attract birds, mainly because grasses do not provide a suitable condition for seed dispersal agents (Vieira et al., 1994; Nepstad et al., 1996). Grasses may however provide perching structure for smaller birds bringing in smaller seeds. Slocum (1997) found that smaller tree seeds (< 3 mm) arrive more than 450 times as frequently as large seeds (> 10 mm) in pasturelands, however they rarely establish among the established neighbouring grass species, mainly because energy and nutrient reserves are too small to quickly produce a extensive root system (Nepstad et al., 1996). Studies have been conducted to examine whether logs in pasturelands create a suitable site for new seedlings recruitment. Low cool temperature, wet, and shady conditions were experienced under the edges of dead logs (Slocum, 2000). Slocum (2000) also found that woody densities in fern patches and logs were five and eight times higher, respectively, as in grass areas. In addition, these logs can decompose slowly. Grass species may find it more difficult to establish on the decomposing substrate than tree seedlings (Slocum, 2000). Similarly Lawton and Putz (1988), and Harmon and Franklin (1989) also report that logs could provide a competition free zone for tree seedlings. Furthermore, Holl (1998) examined whether two kinds of artificial perching structures (crossbar and branch) attract birds. He concluded that birds were attracted to branches and crossbars, but the questions yet to be answered are (1) can we apply this technique to a large area? (2) do we need to clear grasses prior to the treatment or can we use pioneer species branches with mature seeds instead of logs?

Discussion

Conversion of abandoned pasturelands into secondary forest is a major challenge for restoration ecologists. It is an extremely difficult task to predict how long it will take for abandoned pasturelands to become secondary forest. Time scale and success are dependent on several factors: soil disturbance, previous land management, surrounding matrix, species selection and their characteristics features, pre- and post-restoration weed management, seed supply from existing primary forest, and avifauna and mammal activity (Zimmerman et al., 2000; Holl, Loik, Lin, & Samuels, 2000). In this review we looked at five restoration techniques: direct seeding, seedling transplants, cuttings, plantations (using either seedlings or direct seeding), and artificial perching structures. However, only two techniques have been used widely: seedling transplant and plantation as restoration pathways for rainforest. Little is know about direct seeding, stem cuttings, and creating artificial perching structures.

Most of degraded and abandoned pasturelands are inhospitable for tropical rainforest primary and secondary species seeds to germinate. As previously noted these lands may take a considerable number of years to become secondary forest. It could be argued that these lands may never become secondary forest (Uhl et al., 1988). To accelerate the recovery process some sort of manipulation is essential. Kellman (1980), Uhl, Jordan, Clark, and Herrera (1982), Guevara, Purata, and Van der Maarel (1986) and Chapman and Chapman (1999) suggest cuttings in plantations may act as dispersal foci, and have recommended that cuttings may be an alternative pathway to promote regeneration of primary or secondary forest species. However, information on cuttings and their ecological and economic effectiveness is scarce.

Slocum (2000) suggests that logs and fern patches can create a suitable condition and avenue for secondary species to colonise. Cohen, Singhakumara, and Ashton (1995) report that disturbing (clean weed, root removal and till) *Dicranopteris linearis* fernlands soil could accelerate the germination of herb, shrubs and trees seeds. However seedlings recruited from the disturbed fernlands were dominated by herb, sedge, and grass species.

Several studies have focused on plantations as a pathway for rainforest. This has widely been accepted by farmers and ecologists. However, success is dependent on two major factors: species selection and demand for the cash crop in later years. Therefore, demand for the cash crops should be carefully calculated well ahead. Species selection is another area for consideration, some studies recommending that use of native timber species is important while others suggest, use of exotic trees. Chapman and Chapman (1996), studied exotic tree species as plantation crops to conserve native species communities. Engel and Parrotta (2001) evaluated the combination of restoration techniques in degraded lands by using direct seeding of plantation species as a pathway for restoration. They concluded that, direct seeding can be a risky, but plausible alternative to a high cost approach in transforming grassland to plantation. As Sun et al. (1995), Butterfield (1995) and Engel and Parrotta (2001) also emphasised, there is a need for further development and research on the species selection and their seed germination capacity under natural systems prior to direct broadcasting in grasslands.

Considerable restoration work has been undertaken using only seeding (either single species or combinations pioneer species or combinations of pioneer and secondary species). The ultimate aim of all restoration work is to create an 'ideal' microclimate condition. As Goosem and Tucker (1995) proposed, species selected for the restoration programs must withstand extreme conditions, be attractive to wildlife, must reach reproductive stage early and be fast growing. By exhibiting these features, ideal pioneer species in a restored site can attract a wider range of wildlife populations, which are primary forest dispersal agents (Uhl, 1987; Willson & Crome, 1989; Vieira et al., 1994). As Innis (1989) suggest further study is essential in determining the species that have the necessary features. As several studies have pointed out, microclimate created by these artificially planted seedlings or cuttings are vital for primary forest species to colonise. This 'ideal' condition can be provided by the canopy architecture. The question yet to be answered is: what kind of canopy architecture we are looking for: a single layer or multi-strata? If we want to create a multi-strata canopy layer, we need to select different growth rate pioneer species. What about the species that are going to grow on the edges, what kind of canopy architecture should they have?

As previously described, increasing seed input into abandoned pasturelands by attracting avifauna, may speed up the recovery process (Holl, 1998). The major challenge is to attract birds into these inhospitable landscapes. One possible way to attract birds is by providing suitable perching structures. As Holl et al. (2000) pointed out, although artificial perching structures are focal points for birds to perch and led to increased seed dispersal into these abandoned lands, seeds that were brought in did not germinate or seeds that germinated did not survive, mainly because of competition. He demonstrated, that creating artificial perching structures alone did not accelerated the recovery process.

Conclusion

In conclusion, while a considerable number of government and non-government organisations have been dynamically working to restore abandoned and degraded pasturelands by using seedling transplant and plantations techniques, our review shows that there is immediate need for further research and development on restoration techniques. In particular examination of ecological and economic effectiveness of: direct seeding, stem cuttings using native pioneer or climax species and simple manipulation such as displacing branches of pioneer species with mature seeds on abandoned and degraded pasturelands and artificial perching features to accelerate natural regeneration. High density and diversity of natural recruitment on these restoration sites is an essential to reach the secondary forest, but, without faunal and mammal involvement, this process will be slow. In addition to current restoration techniques we have also proposed additional strategies as potential restoration pathways for rainforest. As Engel and Parrotta (2001) showed, combining two or three restoration techniques may be a sensible way to accelerate the recovery process. Before we apply these strategies on a larger scale, study in a wider array of landscapes is necessary. Therefore, research and development on restoration techniques in degraded and abandoned pasturelands is essential.

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